Investigating the Effect of SiC Nanoparticles on the Shear Strength of Friction Stir Lap Welded 7075 Aluminum Alloy

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ABSTRACT

In this paper, the effect of including Silicon Carbide nanoparticles in the weld zone on the maximum shear strength of friction stir lap welded 7075 aluminum alloy is investigated, both experimentally and numerically. This objective is carried out by studying the effects of rotational and transverse speeds, tilt angle, the shape of the tool and the penetration depth. The numerical investigation is based on developing an FE model by means of Deform and ABAQUS to simulate the welding procedure, which results are verified by the experimental findings. Experimental procedure is designed based on Taguchi method. The verification of the developed FE model shows that the simulation results are in proper agreement with the experimental findings. In general, including Silicon Carbide nanoparticles in the weld zone can increase the maximum shear strength up to 24%, compared to the case of where the specimens are welded without Silicon Carbide. Furthermore, applying the threaded tapered tool leads to higher shear strength in comparison with the squared shape tool, i.e., the strength of the specimens welded by threaded tapered tool are 4 to 5% higher without Silicon Carbide inclusion and 4 to 7.5% higher with Silicon Carbide, compared to the same case welded by squared tool. In addition, while the rotational speed has the highest influence on the findings, the tilt angle does not affect the results that much.

KEYWORDS

Friction stir welding, 7075 aluminum alloy, Finite element modeling, Silicon Carbide nanoparticles, Taguchi method.

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1. Introduction

Aluminum has been of interest to designers and engineers due to its unique properties such as a high strength-to-weight ratio, flexibility and formability, high corrosion resistance, and high electrical and thermal conductivity. Applying aluminum in various industries such as aerospace, automotive, and transportation has led to the construction of novel structures.

Despite the widespread applications of aluminum, the welding of its alloys (especially those related to the aerospace industry) are limited due to defects which appear during the welding processes. This issue is so serious which has made some aluminum alloys to be generally classified as non-weldable due to very low strength in their solidified structure and the occurrence of defects such as porosity in the weld zone.

Friction stir welding (FSW) is a solid-state welding process which has originally been introduced for welding of 2xxx, 6xxx and 7xxx aluminum alloys [1]. In friction stir welding, a non-consumable rotating tool is attached to a machine similar to a milling device. The tool is pressed to the two base metal pieces and is then rotated with a simultaneous linear movement along the contact axis of the two pieces. These rotational and linear movements generate heat and cause severe local plastic deformation in the welded area, bringing the joint region to a paste-like state. As a result of the rotational movement of the pin of the tool, the pasty materials mix together, enabling the formation of a welding joint between the pieces.

Among the main achievements of friction stir welding are low distortion, elimination of melting-related defects, and high joint strength. Even materials considered unweldable with conventional techniques can be welded using this method [2, 3]. In the friction stir welding process, considering the different geometries of the tool, the movement of materials around the tool pin can be quite complex. This complexity may negatively affect the quality of the final microstructure of the joint area, resulting in reduced strength of the resulting welded joint [4]. One of the strategies to ensure the high quality of the microstructure in the joint area during aluminum friction welding is based on taking advantage of the concept of aluminum matrix composites [5]. Considering the capabilities of this group of materials, it can be expected that applying a secondary material such as silicon carbide (SiC) or aluminum oxide in the weld area would improve the quality of the resulted joint [6]. These unique advantages have turned FSW of metal matrix aluminum alloys into a developing field of research [7-10]. The general finding in all these researches is the fact that including a secondary phase in the weld zone will improve the strength and quality of the resulted welded joint. In addition, in order to reduce the costs of experimental procedures, some researchers have focused of finite element modelling of FSW in nano-reinforced aluminum alloys [11-13].

In this paper, the effect of SiC nanoparticles on the shear strength of friction stir lap welded 7075 aluminum alloy is studied, both experimentally and numerically. For this purpose, the welding process and the resulting material mixing were simulated as a three-dimensional model using the Deform software, where the thermal history of the welding process was. The thermal history was then used as the input for the Abaqus software, in which the cooling process was simulated. The cooled sample in Abaqus was subjected to tensile loading, and the shear strength of the resultant weld was determined. The welding process was simulated in the presence and absence of the SiC nanoparticles. Subsequently, to validate the numerical model, the maximum shear strength obtained from the simulations was measured and compared to the results from experimental tests. The parameters studied in this study are the tool pin shape, tool indentation depth, rotational speed, linear speed, and tool tilt angle.

2. Materials and Experimental Procedure

To prepare the test samples, 7075 aluminum sheets measuring 80×110 mm^2 with a thickness of 3 mm were initially cut for the FSW process. To ensure the proper mixing of SiC powder in the weld zone, a 60 mm groove of 1 mm width and 2 mm of depth was machined on each base metal sheet along the weld line. The SiC powder was first mixed with alcohol to form a paste. Then, the grooves were filled with SiC powder, and the powder was compacted in the grooves by means of a thin sheet. Two different tool pins are built and are used in the experimental tests, a square pin and a conical pin. The resulted welded specimens are then tested in a tensile test machine, where the shear strength of the joints is determined. The resulted welded specimen is presented in Figure 1.

Figure 1. The resulted welded specimen

3. Finite Element Modelling

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as the input for the Abaqus software, in which the cooling process was simulated. The cooled sample in Abaqus was subjected to tensile loading, and the shear strength of the resultant weld was determined.

4. Results and Discussion

Based on the obtained results, it was determined that including of SiC nanoparticles has led to an increase of 21 to 24 percent in the shear strength of the welded joint. This phenomenon occurs since the SiC nanoparticles positively affect the microstructure of the weld area. A sample of shear strength test result is demonstrated in Figure 2, where the effect of including SiC in the weld area is compared to the case which the metal sheets are welded in the absence of SiC. The effects of different process parameters on the shear strength of the welded joint are studied by means of the FEM model. A sample for the effect of the rotational speed of the tool is presented in Figure 3.

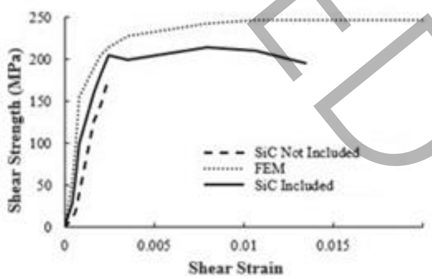

Figure 2. Shear strength for the welded specimens

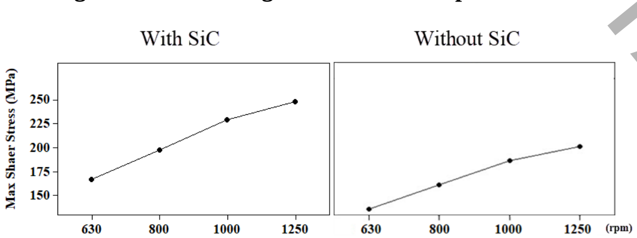

Figure 3. The effect of the tool rotational speed on the shear strength of the resulted joint

5. Conclusions

In the current research, a numerical and experimental study has been conducted to determine the effect of including SiC nanoparticles on the shear strength of the welded joint obtained from the friction stir welding process of 7075 aluminum in the lap joint configuration. The obtained results show that the presence of SiC in the weld area improves the shear strength of the resulted joint up to 24%.

6. References

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